

Top Quark Mass Measurement at CDF Run II.

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Abstract. CDF has resumed the top quark mass measurement with upgraded detectors and Tevatron complex. High statistics should allow us to determine the top mass with an uncertainty of a few GeV/c^2 by the end of Run II. The current measured value, using an integrated luminosity of $\sim 108 \text{ pb}^{-1}$, is $177.5^{+12.7}_{-9.4} (\text{stat.}) \pm 7.1 (\text{syst.}) \text{ GeV}/c^2$ (lepton + jets with one b-jet tagged mode: the current best mode), which is consistent with RunI measurements.

PACS. 14.65.Ha Top quark mass measurement

1 Introduction

The top quark was discovered at the Fermilab by the CDF and D0 experiments in 1995 [1]. It is surprising that this quark has such a large mass, $\sim 175 \text{ GeV}/c^2$ [2], and a Yukawa coupling constant ~ 1 .

The top quark mass measurement is one of the most fascinating and important physics topics at CDF Run II. It provides a constraint of the Higgs boson mass as well as the measurement of a basic standard model parameter. CDF Run II aims to determine the top mass with a few GeV/c^2 accuracy. Together with precision knowledge of the W boson mass ($30 \sim 40 \text{ MeV}/c^2$ accuracy), this provides a $\sim 30 - 40\%$ constraint on the Higgs mass (M_H). To achieve this goal, CDF has improved its silicon detector to increase the b-quark tagging efficiency, which is very crucial for identifying top quark decays. Lepton acceptance was also increased by the detector upgrade.

This article describes the top quark mass measurement: selection of the top quark signal (section 2), the method for determining the top quark mass (section 3), and current results (section 4).

2 Selection of top quark events

Since the top quark decays to a W boson and a b quark with $\sim 100\%$ branching ratio, there are only a small number of final states to be considered. For simplicity, we only describe the most important $t\bar{t}$ decay channel, $t\bar{t} \rightarrow WbW\bar{b} \rightarrow l\nu bj\bar{j}\bar{b}$. This channel provided the best top quark mass measurement among all decay modes in RunI, and has given the earliest result in Run II.

The event selection criteria are as follows:

- (1) The event passes the high- P_T electron or muon trigger,

- (2) Lepton $E_T > 20 \text{ GeV}$ and $\cancel{E}_T > 20 \text{ GeV}$, then either

- (3) Three jets with $E_T > 15 \text{ GeV}$ and $|\eta| < 2.0$, and another jet with $E_T > 8 \text{ GeV}$ and $|\eta| < 2.0$, with at least 1 jet tagged as a b-jet based on finding a secondary vertex. or

- (4) All four jets satisfy a tight requirement ($E_T > 15 \text{ GeV}$ and $|\eta| < 2.0$), but there is no tag requirement (pre-tagged sample).

(Here E_T is transverse energy, P_T is transverse momentum, \cancel{E}_T is missing transverse energy, and η is pseudorapidity.)

After these cuts, the background fraction is already small ($\sim 15\%$) for b-jet tagged events, while the pre-tagged sample still is $\sim 50\%$ background. The main background comes from W boson plus heavy quarks (i.e. $Wb\bar{b}$) in the former case, while W boson + light quarks is the main background in the latter case.

3 Determination of the top quark mass

There are two steps in measuring the top quark mass. The first is to use a constrained fit to determine the top quark mass on an event-by-event basis. The other is to measure the background fraction and extract an ensemble top mass using a log-likelihood method. The following two subsections describe these steps.

3.1 Constrained fit for event kinematics

The $t\bar{t}$ events have the decay chain mentioned above, namely $p\bar{p} \rightarrow t\bar{t}X \rightarrow WbW\bar{b}X \rightarrow l\nu bj\bar{j}\bar{b}X$. There are five decay vertices in this chain, corresponding to 20 kinematic equations (energy and momenta conservation at each vertex) for the 21 unknowns (the 4-momenta of the t , \bar{t} , and

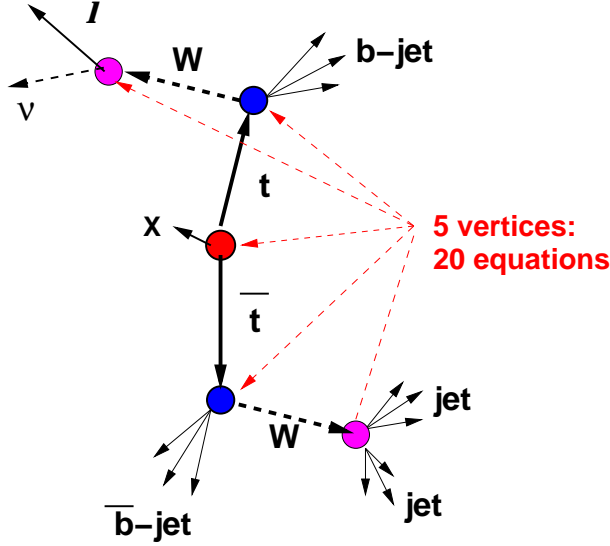


Fig. 1. The schematic view of a top quark decay. There are five vertices and 20 kinematic equations.

the two W 's, the 3-momentum of the ν , and the energy and z momentum of X) (Fig. 1). Adding the W boson mass ($80.423 \text{ GeV}/c^2 : [3]$) constraints, $M_{l\nu} = M_{jj} = M_W$, and the top quark mass constraint, $M_t = M_{\bar{t}}$, provides a two parameter overconstrained χ^2 fit.

Another issue is choosing among the multiple solutions. The four observed jets must be assigned to the final state quarks. For pre-b-tagged events, any of the four jets can be assigned to the b quark, with one of the remaining three assigned to the \bar{b} quark. That gives 12 combinations. In addition, there is a quadratic ambiguity when solving for the z momentum of the ν , giving a total of 24 possible solutions. Even in b-tagged events, there still are 12 combinations. The combination with the best fit χ^2 is chosen for the jet assignments and the z component of the ν momentum.

3.2 Likelihood fit to deduce the top mass and background fraction

The final step in determining the top quark mass is a likelihood fit of the individual event masses to the sum of signal and background templates, with the fit parameter being the background fraction. A fit is carried out at each top mass, and the minimum of the negative-log-likelihood determines the final reported top mass.

4 Results

In this paper, we show three top quark mass measurement results. One uses b-tagged events, the second one uses events without a b-tag requirement, and the third uses events that have two leptons (ee , $e\mu$ or $\mu\mu$) in the event. This latter final state is not discussed in detail here; only the number of events and the extracted mass are presented.

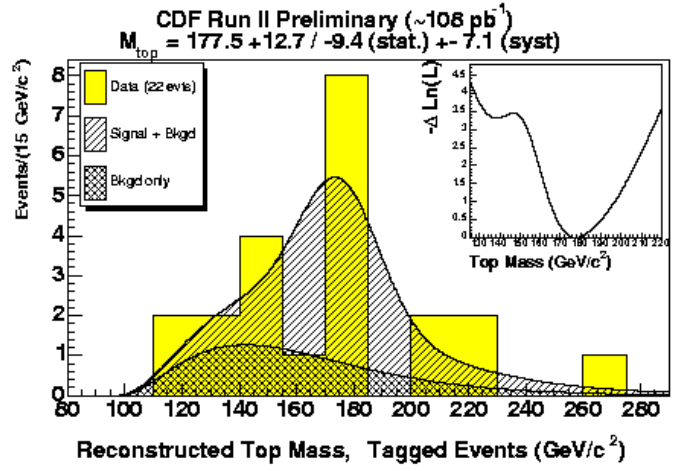


Fig. 2. The reconstructed top quark mass from the constrained fit described in subsection 3.1. There are 22 events containing a b-tagged jet. This figure also shows the mass distribution from the log-likelihood fit for the best fit top mass. The top-right figure shows the $-\Delta \ln(L)$ as a function of top mass.

4.1 Results from b-tagged events

Currently, an integrated luminosity of 108 pb^{-1} is available in this analysis mode. Twenty-two candidates are found. Fig. 2 shows the reconstructed mass using the constrained χ^2 fit mentioned in subsection 3.1. The histogram shows the b-tagged data. The best fit curve from the log-likelihood fit is also shown. One can see the templates for the signal and background scaled to the fit fractions. The best fit mass from this dataset is $177.5^{+12.7}_{-9.4} \text{ (stat.)} \pm 7.1 \text{ (syst.) GeV}/c^2$

4.2 Results from the pre-b-tag sample

In this mode, we use 72 pb^{-1} of integrated luminosity. Thirty-three events are reconstructed as $t\bar{t}$ and fitted as a superposition of the top and W +jets background. The result of this fit is shown in Fig. 3. One sees that this sample has a much larger background fraction than the b-tagged sample.

The best fit mass from this sample is $171.2 \pm 13.4 \text{ (stat.)} \pm 9.9 \text{ (syst.) GeV}/c^2$

4.3 Results from the di-lepton mode

There are 6 di-lepton events corresponding to a 125.8 pb^{-1} integrated luminosity. This mode has very small background but also small statistics due to the additional $W \rightarrow l\nu$ branching ratio. The analysis using this sample gives: $175.0^{+17.4}_{-16.9} \text{ (stat.)} \pm 8.4 \text{ (syst.) GeV}/c^2$.

Table. 1 summarizes these results.

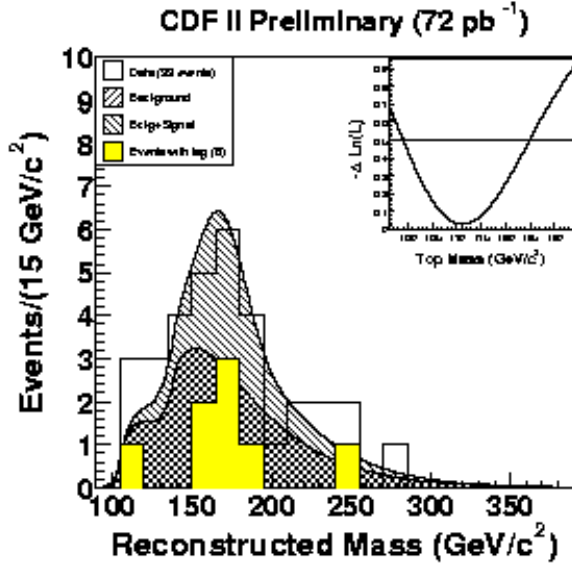


Fig. 3. The reconstructed top quark mass using 33 pre-b-tagged events. The shaded histogram shows the b-tagged events within this sample. Signal and background templates for the fit are also shown. The top-right figure shows $-\Delta\text{Ln}(L)$ as a function of top mass.

Table 1. Summary of top quark mass measurements at CDF Run II.

sample	best fit value
b-tagged	$177.5^{+12.7}_{-9.4}(\text{stat.}) \pm 7.1(\text{syst.}) \text{ GeV}/c^2$
pre-b-tag	$171.2 \pm 13.4(\text{stat.}) \pm 9.9(\text{syst.}) \text{ GeV}/c^2$
di-lepton	$175.0^{+17.4}_{-16.9}(\text{stat.}) \pm 8.4(\text{syst.}) \text{ GeV}/c^2$

Table 2. Current uncertainties for the top quark mass measurement using the b-tagged sample

source	size
statistical	$+12.7_{-9.4} \text{ GeV}/c^2$
jet scale	$6.2 \text{ GeV}/c^2$
MC modeling	$1.0 \text{ GeV}/c^2$
generator	$0.6 \text{ GeV}/c^2$
initial state radiation	$1.3 \text{ GeV}/c^2$
final state radiation	$2.2 \text{ GeV}/c^2$
parton distribution functions	$2.0 \text{ GeV}/c^2$
background	$0.5 \text{ GeV}/c^2$
b-tagging	$0.1 \text{ GeV}/c^2$

5 Perspectives for reducing systematic uncertainties

To achieve the aimed accuracy for the top mass in Run II, there are lots of things to do. To see what are the key issues, we show the current uncertainties for the b-tagged sample in table 2.

The statistical error will be reduced by combining all the independent analysis modes as well as using the full Run II luminosity ($>2.0 \text{ fb}^{-1}$), more than a factor of 20 beyond the integrated luminosity used here. Among the systematic uncertainties, the most significant one comes from the jet energy scale uncertainty. To reduce this, a lot of effort is under way to better understand the detector response, to maintain the detector, to calibrate the jet energy scale in new ways and so forth. Studying $Z \rightarrow b\bar{b}$ events and the reconstructed dijet W boson mass in top events are expected to be quite useful for improving the jet energy calibration.

6 Summary

CDF has resumed measuring the top quark mass with the upgraded Run II detector and Tevatron. We find $177.5^{+12.7}_{-9.4}(\text{stat.}) \pm 7.1(\text{syst.}) \text{ GeV}/c^2$ for the top quark mass employing $\sim 108 \text{ pb}^{-1}$ integrated luminosity (lepton + jets decay with one b-jet tagged mode). This value is clearly consistent with the Run I measurement.

The goal of CDF in Run II is to reduce the uncertainty for this measurement to a few GeV/c^2 . To achieve this, there are many things to do, especially reducing the uncertainty in the jet energy measurement. With these improvements, CDF will provide an important top quark mass measurement by the end of the Run II.

References

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